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Welding Defects and Rectifications on Aerospace Metal


Ch.Isaac
B.Tech (Mechanical Engineering), Hyderabad Institute of Technology and Management, Hyderabad, Telangana, India.


K.Mahesh
B.Tech (Mechanical Engineering), Hyderabad Institute of Technology and Management, Hyderabad, Telangana, India.


V.Shiva Prasad
B.Tech (Mechanical Engineering), Hyderabad Institute of Technology and Management, Hyderabad, Telangana, India.


Venkata Phanibabu.V
Assistant Professor, Department of Mechanical Engineering, Hyderabad Institute of Technology and Management, Hyderabad, Telangana, India.

Abstract:

Welding is the process of joining two or more pieces of metal to make them act as a single piece. Welding is widely used for joining different materials such as steels, Aluminum and its alloys, magnesium and its alloys, copper and its alloys, welding of dissimilar metals for Aerospace components. Possible defects in welding are Cracks, distortion, incomplete penetration, inclusions, porosity and blow holes, poor fusion, poor weld bead appearance, spatter etc.Non-destructive tests of weld such as visual inspection, leak tests, radiography, magnetic particle inspection, fluorescent penetrant inspection and ultrasonic inspection, In order to reuse the weld defected components the defect identification will be done using the above methods , necessary repair will be carried out . After repair, inspection will be done and establish the defect free welding.

I. INTRODUCTION:

Welding is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone, and with or without the use of filler material.Welding is used for making permanent joints. It is used in the manufacture of automobile bodies, aircraft frames, railway wagons, machine frames, structural works, tanks, furniture, boilers, general repair work and ship building.

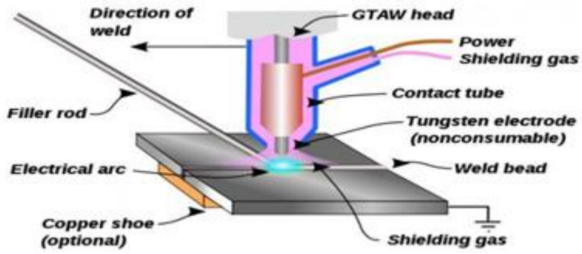

Fig 1: TIG welding process

Fusion Welding Processes:

The surfaces of two components to be joined are cleaned, placed close together and heated while being protected from oxidation. A pool of molten metal forms and connects the components; a filler rod may be used to add metal to the joint. This category covers a very wide range of processes, some of which are considered in more detail later.

Solid State Welding:

The metals to be joined do not melt, they are heated, usually by friction heating generated by sliding the parts together under a normal load, this softens the metals and removes surface contamination. The sliding is then stopped, the normal load is increased and the two surfaces join together. Friction welding is the main process in this class and is widely used to join ax symmetric components in two different types of steels. Examples include engine valves where a heat resistant alloy head is required, but steel that will slide well in the guide is needed for the stem.

Welding On Aluminum Alloys:

The existence of aluminum (Al) was postulated by Sir Humphrey Davy in the first decade of the nineteenth century and the metal was isolated in 1825 by Hans Christian Oersted. It remained as somewhat of a laboratory curiosity for the next 30 years when some limited commercial production began, but it was not until 1886 that the extraction of aluminum from its ore, bauxite, became a truly viable industrial process. The method of extraction was invented simultaneously by Paul Heroult in France and Charles M. Hall in the USA and this basic process is still in use today. Because of its reactive nature aluminum is not found in the metallic state in nature but is present in the earth's crust in the form of different compounds, of which there are several hundreds. The most important and prolific is bauxite.

The extraction process consists of two separate stages, the first being the separation of aluminum oxide,Al2O3 (alumina), from the ore, the second the electrolytic reduction of the alumina at between 950 °C to 1000 °C in cryolite (Na3AlF6). This gives an aluminum, containing some 5–10% of impurities such as silicon (Si) and iron (Fe), which is then refined either by a further electrolytic process or by a zone-melting technique to give a metal with a purity approaching 99.9%.

At the close of the twentieth century a large proportion of aluminum was obtained from recovered and remelted waste and scrap, this source alone supplying almost 2 million tonnes of aluminum alloys per annum in Europe (including the UK) alone. The resulting pure metal is relatively weak and as such is rarely used, particularly in constructional applications.To increase mechanical strength, the pure aluminum is generally *alloyed* with metals such as copper (Cu), manganese (Mn), magnesium (Mg), silicon (Si) and zinc (Zn). One of the first alloys to be produced was aluminum–copper.

Characteristics of aluminum:

The difference in melting points of the two metals and their oxides,the oxides of iron all melt close to or below the melting point of the metal; aluminum oxide melts at 2060°C, some 1400°C *above* the melting point of aluminum. This has important implications for the welding process, as will be discussed later, since it is essential to remove and disperse this oxide film before and during welding in order to achieve the required weld quality. The oxide film on aluminum is durable, highly tenacious and self-healing. This gives the aluminum alloys excellent corrosion resistance, enabling them to be used in exposed applications without additional protection. This corrosion resistance can be improved further by *anodizing* – the formation of an oxide film of a controlled thickness.

Aluminum Alloys:

Many aluminum alloys have been developed for the TIG welding aluminum process. The most popular welding aluminum is either pure aluminum 1xxx or an aluminum manganese alloy 3003. The repair or fabrication of aluminum is done with aluminum brazing (lower cost, stronger welds), using HTS-2000 brazing rods.

They are identified in a 4 digit system with the first digit indicating the metal alloyed with the aluminum:

- 1xxx - 99% pure aluminum, no alloy
- 2xxx - aluminum copper alloy
- 3xxx - aluminum manganese alloy
- 4xxx - aluminum silicon alloy
- 5xxx - aluminum magnesium alloy
- 6xxx - magnesium, silicon and aluminum alloy
- 7xxx - zinc and aluminum alloy
- 8xxx - tin or other metal and aluminum.

TIG Welding:

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds,

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do not require it. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma.

Development:

After the discovery of the short pulsed electric arc in 1800 by Humphry Davy and of the continuous electric arc in 1802 by Vasily Petrov, arc welding developed slowly. C. L. Coffin had the idea of welding in an inert gas atmosphere in 1890, but even in the early 20th century, welding non-ferrous materials such as aluminum and magnesium remained difficult because these metals react rapidly with the air and result in porous, dross-filled welds. Processes using flux-covered electrodes did not satisfactorily protect the weld area from contamination. To solve the problem, bottled inert gases were used in the beginning of the 1930s. A few years later, a direct current, gas-shielded welding process emerged in the aircraft industry for welding magnesium.

Electrode:

The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish—clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them optimal for heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 millimeters (0.02 and 0.25 in), and their length can range from 75 to 610 millimeters (3.0 to 24.0 in).

Applications:

While the aerospace industry is one of the primary users of gas tungsten arc welding, the process is used in a number of other areas. Many industries use GTAW for welding thin work pieces, especially nonferrous metals. It is used extensively in the manufacture of space vehicles, and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry. In addition, GTAW is often used to make root or first-pass welds for piping of various sizes. In maintenance and repair work, the process is commonly used to repair tools and dies, especially components made of aluminum and magnesium. Because the weld metal is not transferred directly across the electric arc like most open arc welding processes, a vast assortment of welding filler metal is available to the welding engineer.

II. Welding Process on Aluminum Alloy:

Type of the welding: Tungsten inert gas welding(TIG) using A.C. source.
Material used: Aluminum alloy 5083(composition of Al and Mg).
Thickness of the material: 5mm.
Type of joint: single V butt joint.
Filler material: Aluminum alloy 5356.

PROCEDURE

Step 1: Pre-weld surface cleaning:

- Clean the material using Acetone and brushing should be done.
- *Pickling process* should be done by using chemicals(sodium hydroxide(NaOH),nitric acid(HNO3) and demineralized water).Dip the material in NaOH for 2-3 secs then clean the material with demineralized water. Then dip in HNO3 for 3 seconds and finally clean with demineralized water.
- After pickling process,brushing and acetone cleaning should be done.
- Oil,grease,paint,moisture,oxide coating and all other continents should be thoroughly removed by cleaning,brushing and pickling processes.

Step 2: Edge preparation:

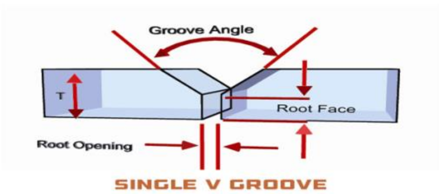

Fig 2: Edge Plate Preparation

Step3: Power supply and Equipment:

A.C. source is used for TIG welding on aluminum alloy(5083).

1st Plate Specifications:

- First root layer amperage - 115Amps.
- First Root layer time – 3mins
- Second root layer amperage – 120Amps
- Second root layer time – 4mins 10sec
- Voltage used – 16V

2nd Plate Specifications:

- First root layer amperage - 125Amps.
- First Root layer time – 4 mins
- Second root layer amperage – 130Amps
- Second root layer time – 4mins 30sec
- Voltage used – 18V.

3rd Plate Specifications:

- First root layer amperage - 125Amps.
- First Root layer time – 4 mins 30sec
- Second root layer amperage – 130Amps
- Second root layer time – 4mins 50sec
- Voltage used – 18V.

Equipment:

1. Shielding Gas
   - Argon is generally used for TIG welding aluminum
   - Helium is sometimes employed with higher speeds and for thicker sections
2. Welding Electrode
   - For AC welding unalloyed tungsten electrode is recommended.
   - Unalloyed tungsten electrodes minimize inclusions in the weld bead.
   - When welding with AC the tip of the electrode should be hemi spherical
3. Filler Rod
   - Filler rod aluminum alloy 5356 is used to weld aluminum alloy 5083

Welding Process:

1. Aluminum alloy plates were fixed to the weld table using fixtures. Root gap to maintain to allow penetration. The root gap which was taken is 2mm.
2. The operator has set the current flow and voltage in the welding machine
3. The operator held the welding torch in one hand and the filler rod in the other hand
4. Both hands moved in unison, with a slight backward and forward motion along the joint.
5. A short arc helped obtain sufficient penetration and avoid under cutting. Arc length is kept approximately equal to the tungsten electrode diameter
6. The TIG welding torch is kept vertical to the centre line of the joint, at forehead angle of about 75-85^0 from the plain of the work. Arc is directed more towards the thick section when welding unequal sections.
7. The first layer of weld was executed in 3mins after which the second layer was executed in 4mins 10sec
8. The welder finished the welding according to the procedure.
9. The excess weld portion was removed by grinding process.
10. The finished plates have been forwarded to Nondestructive testing (NDT) for testing of welded plates.

III. NON DESTRUCTIVE TESTING (NDT) METHODS

Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used. In contrast to NDT, other tests are destructive in nature and are therefore done on a limited number of samples ("lot sampling"), rather than on the materials, components or assemblies actually being put into service.

These destructive tests are often used to determine the physical properties of materials such as impact resistance, ductility, yield and ultimate tensile strength, fracture toughness and fatigue strength, but discontinuities and differences in material characteristics are more effectively found by NDT.
Today modern nondestructive tests are used in manufacturing, fabrication and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs and to maintain a uniform quality level. During construction, NDT is used to ensure the quality of materials and joining processes during the fabrication and erection phases, and in-service NDT inspections are used to ensure that the products in use continue to have the integrity necessary to ensure their usefulness and the safety of the public.

NDT Test methods are:
Visual inspection
Penetrant test

Visual Inspection

- Visual inspection is the simplest, fastest, economical and most commonly used test for detecting defects on the surfaces of the welded objects.
- The weld surface nd joint is examined visually, preferably with the help of a magnifying lens.
- Visual inspection can help detecting the porosity, blow holes, exposed inclusions, unfilled craters, unfused welds, surface cracks, under cutting, improper profile, dimensional accuracy of welds.

Penetrant Test:
Liquid penetrant examination is one of the most popular Nondestructive Examination (NDE) methods in the industry. It is economical, versatile, and requires minimal training when compared to other NDE methods. Liquid penetrant exams check for material flaws open to the surface by flowing very thin liquid into the flaw and then drawing the liquid out with a chalk-like developer. Welds are the most common item inspected, but plate, bars, pipes, castings, and forgings are also commonly inspected using liquid penetrant examination.

Advantages:

- High sensitivity to small surface discontinuities
- Easy inspection of parts with complex shapes
- Quick and inexpensive inspection of large areas and large volumes of parts/materials
- Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive can all be inspected)
- A visual representation of the flaw are indicated directly on the part surface
- Aerosol spray cans make the process portable, convenient, and inexpensive
- Indications can reveal relative size, shape, and depth of the flaw
- It is easy and requires minimal amount of training.

Disadvantages:

- Detects flaws only open to the surface
- Materials with porous surfaces cannot be examined using this process
- Only clean, smooth surfaces can be inspected. (Rust, dirt, paint, oil and grease must be removed.)
- Metal smearing from power wire brushing, shot blasting, or grit blasting must be removed prior to liquid penetrant examination
- Examiner must have direct access to surface being examined

IV. WELDING DEFECTS AND RECTIFICATION ANALYSIS

- Porosity
- Slag Inclusions
- Incomplete fusion and penetration
- Weld profile
- Cracks

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- Lamellar tears
- Residual stresses

Porosity

- Porosity is the presence of cavities in the weld metal caused by the freezing in of gas released from the weld pool as it solidifies.
- Caused by gases released during melting of the weld area but trapped during solidification, chemical reactions, Contaminants
- They are in form of spheres or elongated pockets.

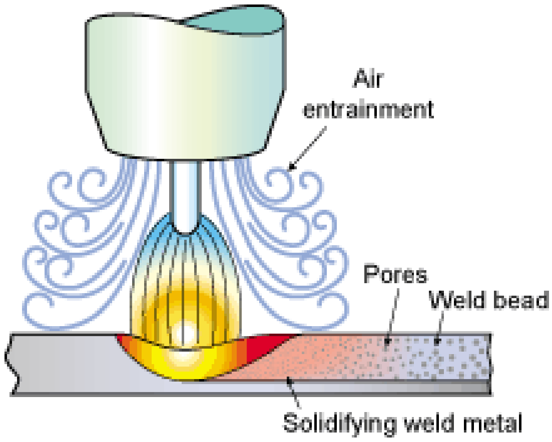

Fig 3: porosity

Remedy:

- Proper selection of electrodes
- Improved welding techniques
- Proper cleaning and prevention of contaminants
- Reduced welding speeds

Slag Inclusions

- Slag is normally seen as elongated lines either continuous or discontinuous along the length of the weld. This is readily identified in a radiograph, Slag inclusions are usually associated with the flux processes, ie MMA, FCA and submerged arc, but they can also occur in MIG welding.
- Compounds such as oxides,fluxes, and electrode-coating materials that are trapped in the weld Zone.

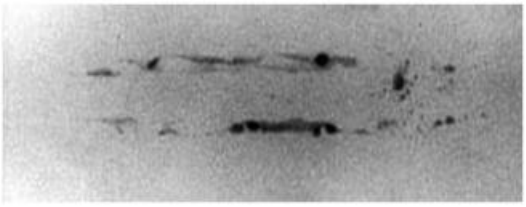

Fig 4: Slag inclusions

Prevention:

- Cleaning the weld bed surface before the next layer is deposited
- Providing enough shielding gas
- Use welding techniques to produce smooth weld beads and adequate inter-run fusion to avoid forming pockets to trap the slag
- Use the correct current and travel speed to avoid undercutting the sidewall which will make the slag difficult to remove
- Remove slag between runs paying particular attention to removing any slag trapped in crevices.
- Use grinding when welding difficult butt joints otherwise wire brushing or light chipping may be sufficient to remove the slag.

Cracks:

Cracks are classified as Hot or Cold.

- Hot cracks – Occur at elevated temperatures
- Cold cracks – Occur after solidification

Factors causing cracks

- Temperature gradients that cause thermal stresses in the weld zone
- Variations in the composition of the weld zone.
- Embrittlement of grain boundaries
- Inability if the weld metal to contract during cooling.

Prevention

- Change the joint design, to minimize stresses from the shrinkage during cooling
- Change the parameters, procedures, the sequence of welding process
- Preheat the components to be welded
- Avoid rapid cooling of the welded components.

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Incomplete Fusion

- The principal causes are too narrow a joint preparation, incorrect welding parameter settings, poor welder technique and magnetic arc blow.
- Insufficient cleaning of oily or scaled surfaces can also contribute to lack of fusion.
- These types of imperfection are more likely to happen when welding in the vertical position.

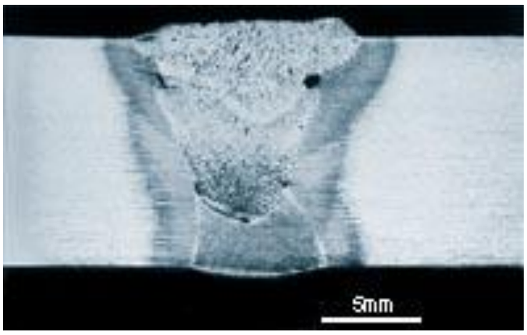

Fig 5: Incomplete fusion

Remedy

- Raising the temperature of the base metal
- Cleaning the weld area, prior to the welding
- Changing the joint design and type of electrode
- Providing enough shielding gas.

Incomplete Penetration or incomplete root fusion:

Incomplete root fusion is when the weld fails to fuse one side of the joint in the root. Incomplete root penetration occurs when both sides of the joint are unfused.Incomplete penetration occurs when the depth of the welded joint is insufficient.

Fig 6:Incomplete penetration

Remedy

- Increasing the heat Input
- In TIG welding, do not use too large a root face and ensure the welding current is sufficient for the weld pool to penetrate fully the root
- Reducing the travel speed during the welding
- Changing the joint design
- Ensuring the surfaces to be joined fit properly

Weld profile:

- Under filling results when the joint is not filed with the proper amount of weld metal
- Undercutting results from the melting away of the base metal and consequent generation of a groove in the shape of a sharp recess or notch
- Overlap is a surface discontinuity usually caused by poor welding practice and by the selection of improper material.

V. CONCLUSION

While joining of the similar metal which is aluminum 5083.The defects which occurred during welding can be identified through radiography,DPT and also by visual observation.These defects can be re-worked and used for intended aerospace applications.

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